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AUTHOR Ho, Yu Chong
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ABSTRACT

The philosophical notions introduced by Charles Sanders Peirce (1839-1914) are helpful for researchers in understanding the nature of knowledge and reality. In the Peircean logical system, the logic of abduction and deduction contribute to our conceptual understanding of a phenomenon, while the logic of induction adds quantitative details to the conceptual knowledge. Although Peirce justified the validity of induction as a self-corrective process, he asserted that neither induction nor deduction can help us to unveil the internal structure of meaning. As exploratory data analysis performs the function of a model builder for confirmatory data analysis, abduction plays the role of explorer of viable paths to further inquiry. Thus, the logic of abduction fits well into exploratory data analysis. At the stage of abduction, the goal is to explore the data, find out a pattern, and suggest a plausible hypothesis; deduction is to refine the hypothesis based upon other plausible premises; and induction is the empirical substantiation. (Contains 55 references.) (Author)

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Abduction? Deduction? Induction? Is there a Logic of Exploratory Data Analysis?

Yu Chong Ho
University of Oklahoma
Internet: YuHo@aol.com

April 4, 1994

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Abstract

The philosophical notions introduced by Charles Sanders Peirce (1839-1914) are helpful for researchers in understanding the nature of knowledge and reality. In Peircean logical system, the logic of abduction and deduction contribute to our conceptual understanding of a phenomenon, while the logic of induction adds quantitative details to the conceptual knowledge. Although Peirce justified the validity of induction as a self-corrective process, Peirce asserted that neither induction nor deduction can help us to unveil the internal structure of meaning. As exploratory data analysis performs the function as a model builder for confirmatory data analysis, abduction plays a role of explorer of viable paths to further inquiry. Thus, the logic of abduction fits well into exploratory data analysis. At the stage of abduction, the goal is to explore the data, find out a pattern, and suggest a plausible hypothesis; deduction is to refine the hypothesis based upon other plausible premises; and induction is the empirical substantiation.

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Abduction? Deduction? Induction?
Is there a Logic of Exploratory Data Analysis?

Yu Chong Ho

Peircean philosophy of science is an abundant intellectual treasure. Charles Sanders Peirce was competent in logic, mathematics and different branches of science, including astronomy, chemistry, physics, geology, and meteorology. He was versed in most of the ancient and contemporary schools of thought in logic (Brent, 1993). Peirces's writings provide many insightful applications to psychologists and educational researchers. The thesis of this paper is that by applying Peircean notion of truth and reality, qualitative and quantitative methods are cooperative rather than competitive. In the view of Peircean logical system we may say the logic of abduction (firstness) and deduction (secondness) contribute to our qualitative or conceptual understanding of phenomena (Hausman, 1993), while the logic of induction (thirdness) adds quantitative details to the qualitative or conceptual knowledge.[1]

Qualitative and Quantitative disparities are centered around the issues of prescriptive and clear-cut answers verses descriptive languages; and single and objective reality verses multiple and subjective realities (Langenbach, M.; Vaughn, C. & Aagaard, L., 1994; Erlandson, Harris, Skipper & Allen, 1993). The gap between qualitative and quantitative research might be filled by multiple approaches which employ abduction, deduction and induction altogether. The first section of this paper will discuss several assumptions of the Peircean philosophical system in an attempt to reconcile the differences in qualitative and quantitative research. The second part of this paper will evaluate the strengths and weaknesses of these three logical processes under Peircean direction.

Premises of Peircean Philosophy of Science

Anti-Cartesian

Anti-skepticism.

One of the assumption of Peircean philosophical system is anti-Cartesian skepticism. DesCartes (1641/1964) doubted everything, even his own existence. In his view, knowledge originates from doubts and questioning. Peirce (1868) rejected the Cartesian tradition by arguing, "We cannot begin with complete doubt." (p. 140) Rather he ensured what Hegelians deny--we don't have to be certain of everything in order to know something. In "The Fixation of Belief," (1877) Peirce said that we are satisfied with beliefs rather than doubts. Although knowledge is fallible in nature, and in our limited lifetime we cannot discover the ultimate truth, we will still fix our beliefs at certain points. This is why Peirce's epistemology is considered the percussor to pragmatism. At the same time, Peirce did not encourage us to relax our mind and not pursue further inquiry. Instead, he saw seeking knowledge as an interplay between doubts and beliefs, though he did not explicitly use the Hegelian term "dialectic."

Unfortunately, William James took Peirce's notion of satisfaction of beliefs but overlooked the struggle between doubts and beliefs. James argued, "The true is the name of whatever proves itself to be good in the way of belief...is only the expedient in the way of our thinking." (1898/1975, p.42; 1909/1927, vii) In other words, for James the issue is not what is truth, but what we believe is truth. Gullvaag said that American pragmatism is, to a great extent, a result of James' misunderstandings of Peirce (cited in Coppock, 1994). Also, John Dewey took Peirce's notion of "fixing beliefs" and develop instrumental pragmatism for "fixing situations." In other words, for Dewey the issue is not what is truth metaphysically, but what would work under a specific circumstance. Peirce strongly resented both James' psychological pragmatism and Dewey's outcome-based instrumentalism, and thus Peirce renamed his

pragmatism as "pragmaticism" in order to distinguish himself from James and Dewey (Smith, 1978).

Anti-foundationalism and Anti-reductionism.

Besides skepticism, Peirce (1868) also disagreed with DesCartes on foundationalism. Peirce showed a firm rejection against the Cartesian posture of laying the foundation of epistemology on the unchanged self-consciousness (I think therefore I am) and innate ideas. DesCartes' discovery of analytical geometry and Cartesian co-ordinates led to the notion that knowledge can be reduced to logico-mathematical methods, which is based on human innate operational structure (Piaget, 1971). For Peirce, reducing our perception of this complex world to certain elements or foundations such as self-consciousness and pure logic, will deny the continuity and universality of events.

Truth and Reality

These issues regarding to foundations are essentially ontological: What is the nature of reality? On what ultimate grounds can knowledge be built? Sometimes Peirce's position seems to be inconsistent in this regard. Peirce stated that hardness is not an attribute of an object until we measure it (1878a). However, this statement should not be interpreted as a position that there is no objective reality. What Peirce implied was that knowledge is a social construct. The concept of hardness is a result of our test and measurement, however, truth is not just a social construct (Parker, 1994).

Peirce made a distinction between truth and reality. Truth is the understanding of reality through a self-corrective inquiry process by the whole intellectual community across time. On the other hand, reality is the existence independent of human inquiry (Wiener, 1969). In terms of ontology, there is one reality. In regard to methodology and epistemology, there is more than one approach and one source of knowledge. Reality is "what is" while truth is "what would be." One of the differences between pragmatism and pragmaticism can be viewed as orientation to truth and reality. Dewey and James adopted a subjective and humanistic

view to truth i.e. knowledge is a human and social construct and it can be known without a transcendental standard. For Dewey "the problem of philosophy is not how we can come to know an external world, but how we can learn to control it and remake it, and for what goals" (Durant, 1926/1961, p.523). In contrast, Peirce introduced a metaphysical dimension into pragmaticism and implied a universal and transcendental standard (Apel, 1981). For Peirce the inquiry of knowledge is a form of free association or creative thinking that resemble the Divine mind (Oakes, 1993), or the Hegelian "Absolute Spirit" (Margolis, 1993).

Knowledge is Cumulative and Self-corrective

Unlike Thomas Kuhn's (1962) emphasis on paradigm shift, Peirce stressed the continuity of knowledge. First, knowledge does not emerge out of pure logic. Instead, it is a historical and social product. As mentioned before, Peirce disregarded the Cartesian attitude of doubting everything. To some extent we have to fix our beliefs on those positions that are widely accepted by the intellectual community (1877).

Kuhn proposed that the pattern of inquiry is a process of new frameworks overthrow outdated frameworks. Peirce, in contrast, considered knowledge to be continuous and cumulative. Rescher (1978) used the geographical-exploration model as a metaphor to illustrate Peirce's idea: The replacement of a flat-world view with a globe-world view is a change in qualitative understanding, or a paradigm shift. After we have discovered all the continents and oceans, measuring the height of Mount Everest and the depth of the Nile river is adding quantitative details to the qualitative understanding. Although Kuhn's theory looks glamorous, as a matter of fact, paradigm shifts might occur only once in a century or a few centuries. The majority of scholars are just adding details to existing frameworks. Knowledge is self-corrective insofar as we inherit the findings from previous scholars and refine them.

Implications of Premises to Qualitative and Quantitative Research

In this paper the intent is not to settle all debates between qualitative and quantitative research. Nevertheless, the preceding premises of Peircean philosophy sheds some light on the dispute.

Pragmatic and Clear Cut Answers?

Quantitative approach is not a quick fix.

First, quantitative research methods are apt to Peirce's pragmaticism rather than James or Dewey's pragmatism. For pragmatic reasons statistics does produce clear-cut answers. However, in a case of hypothesis testing, fixing an alpha cutoff does not imply that the case is closed and no further inquiry is needed. On more than one occasion, I have heard people say that qualitative research is more difficult than quantitative because in the former the data is messy and the answer is not clear-cut. Unfortunately, a decision based upon rejecting the null or not gives a picture that statisticians are finding an easy out or seeking for a simple answer.

Balancing model and error is struggle between belief and doubt.

Quantitative research is neither James' psychologism nor Dewey's instrumentalism. First, the goal of statistics is not to produce a quick fix to make us feel good. Second, statistics will not just stop at what works and what cannot work. Rather, it will go further to find out why something works and why something doesn't. In addition, statisticians who provide a quick fix may not do exploratory data analysis at all. Exploratory data analysis, like qualitative study, handles messy data. The process of balancing smooth and rough, fit and residual, or model and error can be viewed as Peircean's interaction between doubt and belief. The commonality between qualitative study and exploratory data analysis will be discussed later.

Realist and Truth Seeking?

Some writers created the unnecessary polarity of perspective seeking (qualitative research) verses truth seeking (quantitative research) (Langenbach et al., 1994; Erlandson et al., 1993). Langenbach et al. even said that quantitative researchers who accept "truth seeking ontology" contend that ultimately there exists one best answer.

Multiple approaches are not ontological but epistemological.

First, it is doubtful whether statisticians accept that there exists only "one best answer." Second, "one best answer" is not an ontological concern. Asking whether the mansion of a wealthy man has one million dollars is one question; asking which is the best way to break into the house and steal the money is another question. When qualitative researchers look for multiple and subjective realities, this is an epistemological issue. When quantitative researchers accept an objective reality, this is in regard to the ontological dimension. In practice, most quantitative researchers still use multiple approaches to address multiple realities. In other words, quantitative researchers do look for perspectives. As mentioned before, in Peircean system the term "truth" is not the same as ultimate reality. If we refer to quantitative methods as a means of truth seeking, we should see the truth as the understanding of reality, but not the reality itself. We make decisions based upon statistics due to pragmatic reasons--so called fixing our beliefs at certain points. However, we pass our findings to subsequent researchers so that details can be added and mistakes can be corrected.

The nature of knowledge is not social but transcendental.

Qualitative researchers adopt "perspective seeking" and "descriptive language," which are socially constructed. The misuse of this approach may lead to radical nominalism, which was opposed by Peirce (Parker, 1994). Nominalism views the core issue of epistemology as the use of terminology, and there is no logical mapping between the language and the reality. Whether a theory is acceptable or not relies highly on its compatibility

with the "standard language." I would stand with Peirce's pragmaticism--beyond the subjective and humanistic level of understanding of knowledge, there should be a transcendental level at the underlying logic and structure of reality, in Kantian term, the "internal structure of meaning."

Reality is inter-subjectivity.

I would go beyond Peirce to suggest a unity between truth and reality, truth and perspective, and the humanistic world and the transcendental world. Perspective seeking verses truth seeking can be viewed as another version of the subject-object spilt introduced by DesCartes. Barrett (1986) criticized this dualism as unnecessary: Most modern philosophers ranging from phenomenologists to analytic philosophers rejects the Cartesian dichotomy. For modern philosophers, inter-subjectivity is more suitable to epistemology. Knowledge is a result of inter-subjectivity--I am a part of reality, and reality is a part of me; truths carry perspectives, and perspectives contain truths. The world I know is partly shaped by my input, and being who I am is partly caused by the input from the world. In this sense, there isn't a reality entirely independent of human inquiry; neither a perspective without the influence from the world.

Logical-positivism and Reductionism?

Conceptual works can lead to ontological reductionism.

When quantitative research is labelled as "logical-positivism," what people have in their minds is a reduced world of logic and mathematics suggested by Russell and Whitehead (1910). Although many scholars discredit reductionism, Searle (1993) defended the value of ontological reductionism, in which objects of certain types can be shown to consist of nothing but elements of other types. For example, genes can be shown to be composed of nothing but DNA molecules. Searle asserted that in history of science successful causal inferences tend to lead to ontological reductions. When people criticize reductionism, they pinpoint its weakness of leaving essential features out. But an ontological reduction captures the invariant elements that are

sufficient for representing the whole object.

Data compression is a good metaphor to illustrate Searle's position. If I use a software compactor such as Stuffit, Compact Pro or PKZIP to reduce the size of a file, later the entire file can be recomposed without any data truncation. But if I use a "lossy" method such as JPEG or MPEG to pack a graphic file, details will lose at the stage of decompression. One should not decline to use Stuffit or Compact Pro after their pictures lost the image quality through JPEG or MPEG compression. By the same reasoning, one should not disbelief ontological reductionism while they have problems with non-ontological reductionism.

However, the goal of ontological reduction is at the stage of conclusion, not at the process of inquiry. In other words, ontological reduction is the end but non-ontological reduction is the means. Data reduction methods in statistical procedures are no doubt non-ontological reductions i.e statistical numbers resulted in data reduction methods are a distorted representation of the world. Like JPEG and MPEG, data reduction sacrifices some details, but so are other languages and symbols, even "descriptive language." Actually, every research approach is reductive in nature, otherwise the huge chuck of information will be burdensome to researchers. Take the lossy method as an analogy again. Although JPEG and MPEG trim off some pixels during compression, the reconstructed images are still sharp enough to recognize, for the lost details are too small to be detectable by human eyes. The important point is to transmit the whole picture, not the combination of every piece of detail. By the same token, researchers want to see a big picture rather than tons of data.

Peirce recognized the existence of an ontological and metaphysical reality. In regard to quantitative research methods, the inquiry concering the conceptual aspect is capable of pointing to the direction of ontological reduction. In this view, exploratory data analysis, which contributes to the conceptual understanding, has no contradiction with Searle and

Peirce's position.

Quantitative research is not a one-way reduction.

In deed, quantitative research as a whole is harmonious with Searle and Peirce's notions. It is a misunderstanding to see quantitative research as a one way reduction of complex phenomena to numbers. One of the goals of quantitative research is to find the optimal balance between parsimony and goodness of fit. During the process of exploratory data analysis, a careful statistician always goes back and forth to add variables to or take variables out of the model. I see no evidence that statistics is a one way reduction.

Fallibilism

In Peirce's view, knowledge is fallible in nature but continuous inquiry makes knowledge self-corrective. Quantitative understanding builds on qualitative understanding, and they can correct each other. Rescher (1978) interpreted that for Peirce the process of qualitative induction can be correctively monitored by quantitative induction. For instance, as more and more patients are infected with HIV from heterosexual activities, our conception that AIDS is only a disease of homosexuality is changed. Rescher contented that "Peirce is thus at once with Sir Ronald Fisher in declaring that the theory of statistical inference in general, make key contributions to the scientific induction." (p.13)

On the other hand, qualitative understanding can correct quantitative knowledge by pointing out new directions that have been neglected. For example, in economics unempolyment and inflation used to be explained by the Philip's Curve and Fisher equation, but later the phenomenon that high unemployment rate and high inflation rate occur at the same time stimulated the introduction of new theories such as the Supply Side Economics.

Many statisticians are highly aware of the fallible nature of the discipline. Statistics is not just measurement, but is also concerned with measurement error. Many statistical endeavors can be viewed as the effort to find out additional

error in relations to the least error. I see no evidence that statistics is regarded as a form of absolute measurement.

Actually, quantitative and qualitative methodologies share more common grounds rather than conflict in regard to epistemology: They both admit that there is more than one way to approach reality; there is a continuity between qualitative and quantitative understanding; there is a tension between the complex world and the reduced model; there is a fallible nature of all inquiries, and thus conclusions are tentative rather than final. More importantly, they both attempt to break down the data and reconstruct them into a pattern. In the process of pattern-seeking, they both use symbolic representations. Qualitative research applies language while quantitative research employs numbers. Neither is more descriptive or reducing than the other one.

Peircean Logical System

Exploratory data analysis, which aims at suggesting a pattern for further inquiry, contributes to the conceptual or qualitative understanding of a phenomenon. Although it deals with numbers, the ending point is not statistical figures. Rather the product is the hypothetical insight of the essential feature or pattern of an event. In other words, the major concern is not "how much," but "what" and "how."

Abduction, the logic suggested by Peirce, can be viewed as a logic of exploratory data analysis. For Peirce abduction is the firstness (existence, actuality); deduction, the secondness (possibility, potentiality); and induction, the thirdness (generality, continuity). Abduction plays the role of generating new ideas or hypotheses; deduction functions as evaluating the hypotheses; and induction is justifying of the hypothesis with empirical data (Staat, 1993).

Abduction

Abduction is not symbolic logic but critical thinking.

Abduction is to look for a pattern in a phenomenon and suggest a hypothesis (Peirce, 1878a). Despite the long history

of abduction, abduction is still unpopular among texts of logic and research methodology, which emphasize formal logic. Logic is divided into formal types of reasoning (symbolic logic) and informal types (critical thinking). Unlike deduction and induction, abduction is a type of critical thinking rather than symbolic logic, though in the following example abduction is illustrated with symbols for simplification:

The surprising phenomenon, X, is observed.
Among hypotheses A, B, and C, A is capable of explaining X.
Hence, there is a reason to pursue A.

Abduction is not Popperian falsification but hypothesis generation.

This process of inquiry can be well applied to exploratory data analysis. In exploratory data analysis, after observing some surprising facts, we exploit them and check the predicted values against the observed values and residuals. Although there may be more than one convincing patterns, we "abduct" only those which are more plausible.

In other words, exploratory data analysis is not trying out everything. Rescher (1978) interpreted abduction as an opposition to Popper's falsification (1963). There are millions of possible explanations to a phenomenon. Due to the economy of research, we cannot afford to falsify every possibility. As mentioned before, we don't have to know everything to know something. By the same token, we don't have to screen every false thing to dig out the authentic one. Peirce argued that animals have the instinct to do the right things without struggling, we human, as a kind of animal, also have the innate ability to make the right decision intuitively.

Abduction is not hasty judgment but proper categorization.

It is dangerous to look at abduction as impulsive thinking and hasty judgment. In the essay "The Fixation of Belief," Peirce explicitly disregarded the tenacity of intuition as the source of knowledge. Also, exploratory data analysis, as an applications of abduction, is not a permit for the analyst to be

naive to other research related to the investigated phenomena (Anthony, 1994). Peirce strongly criticized his contemporaries' confusion of propositions and assertions. Propositions can be affirmed or denied while assertions are final judgments (Hilpinen, 1992). The objective of abduction is to determine which hypothesis or proposition to test, not which one to adopt or assert (Sullivan, 1991).

For Peirce, progress in science depends on the observation of the right facts by minds furnished with appropriate ideas (Tursman, 1987). Definitely, the intuitive judgment made by an intellectual is different from that made by a high school student. Peirce cited several examples of remarkable correct guesses. All success is not simply lucky. Instead, the opportunity was taken by the people who were prepared:

a). Bacon's guess that heat was a mode of motion;

b). Young's guess that the primary colors were violet, green and red;

c). Dalton's guess that there were chemical atoms before the invention of microscope (cited in Tursman, 1987).

Peirce stated that classification plays a major role in making hypothesis, that is the characters of phenomenon are placed into certain categories (Peirce, 1878b). As mentioned before, Peircean view of knowledge is continuous rather than revolutionary. Abduction does not attempt to overthrow previous paradigms, frameworks and categories. Instead, the continuity and generality of knowledge makes intuition possible and plausible.

Peirce was an admirer of Kant. He endorsed Kant's categories in Critique of Pure Reason (1781/1969) to help us to make judgments of the phenomenal world:

1. quantity (universal, particular, singular);
2. quality (affirmative, negative, infinite);
3. relation (categorical, hypothetical, disjunctive);
4. modality (problematic, assertoric, apodeictic).

Also, Peirce agreed with Kant that things have internal

structure of meaning. Abductive activities are not empirical hypotheses based on our sensory experience, but rather the very structure of the meanings themselves (Rosenthal, 1993). Based on the Kantian framework, Peirce (1867/1960) later developed his "New list of categories."

In short, abduction by intuition, can be interpreted as observing the world with appropriate categories which arise from the internal structure of meanings. The implications of abduction for researchers is that the use of exploratory data analysis is neither exhausting all possibilities nor making hasty decisions. Researchers must be well-equipped with proper categories in order to sort out the invariant features and patterns of phenomena. The statistical method, in this sense, is not only number crunching, but also a thoughtful way of dissecting data.

Deduction

After suggesting a plausible hypothesis, the next stage is to refine the hypothesis with logical deduction. Deduction is drawing logical consequences from premises. The conclusion is true given the premises are true also (Peirce, 1868). For instance,

All As are Bs.

C is B.

Therefore, C is A.

Deduction cannot lead to new knowledge.

First, this kind of reasoning cannot lead to the discovery of new knowledge, because the conclusion has already been embedded in the premise (Peirce, 1900/1960). In some cases the premise may even be tautological--true by definition. Brown (1963) illustrated this weakness by using an example in economics:

An entrepreneur seeks maximization of profits.

The maximum profits will be gained when marginal revenue equals marginal cost.

An entrepreneur will operate his business at the equilibrium

between marginal cost and marginal revenue.

The above deduction simply tells you that a rational man would like to make more money. There is a similar example in cognitive psychology:

Human behaviors are rational.

One of several options are more efficient in achieving the goal.

A rational human will take the option which directs him to achieve his goal (Anderson, 1990).

The above two deductive inferences simply provide examples that a rational man will do rational things. The specific rational behaviors have been included in the bigger set of generic rational behaviors.

Deduction does not specify necessary or sufficient condition.

Second, usually inferences made with deductive methods do not specify whether the premise is a necessary condition, a sufficient condition, or both. For example, rationality is a necessary condition, but not a sufficient condition, of making the correct choice. Sometimes people may fail to select the right alternative because of lack of faith or courage.

Deduction relies on true premises.

Third, deduction is fallible as we cannot logically prove all the premises are true. Russell and Whitehead (1910) attempted to develop a self-sufficient logico-mathematical system. In their view, not only can mathematics be reduced to logic, but logic is the foundation of mathematics. In the traditional hierarchy of knowledge, biology seeks support from chemistry; chemistry needs proof from physics; physics depends on mathematics. The notion that mathematics relies on logic implies that all knowledge can be explained by logic.

However, Godel (1947/1986) found that it is impossible to have such a self-contained system. Any lower order theorem or premise needs a higher order theorem or premise for substantiation and it goes on and on; and no system can be

complete and consistent at the same time.

Peirce reviewed Russell's book Principles of Mathematics in 1903, but he only wrote a short paragraph with vague comments. Nonetheless, based on Peirce's other writings on logic and mathematics, Haack (1993) concluded that Peirce would be opposed to Russell and Whitehead's notion that the epistemological foundations of mathematics lie in logic. It is questionable whether deductive knowledge sound just because the logic or the mathematics stands. No matter how logical a hypothesis is, it is only sufficient within the system; it is still tentative and requires further investigation with outside proof. For instance, according to geometry rules, the sum of three angles inside a triangle is 180 degree. However, if one applies this premise of a two dimensional plane to a three-dimensional world, the deductive conclusion will be totally wrong. When you draws a triangle on this planet such as starting from North Pole to the west of equator, and stop at the east of equator, the sum of three angles can be more than 180 degree.

This line of thought posed a serious challenge to researchers who are confident in the logical structure of statistics. Mathematical logic replies on many unproven premises. For example, the mishmash of null and alternative hypotheses; the disputable computation of effect size; the redundancy of Bartlett's test; the artificial cutoff of alpha level and so on. Statistical conclusions are considered true only given that all premises that are applied are true. As a matter of fact, Kline (1990) found that mathematics had developed illogically with false proof and slips in reasoning. Thus, he called the deductive proof from self-evident principles in mathematics an "intellectual tragedy," (p.3) and a "grand illusion" (p.4).

In recent years many Monte Carlo simulations have been conducted to determine how robust certain tests are, and which statistics should be favored. The reference and criteria of all these studies are within the logico-mathematical system without

any worldly concerns. For instance, Fisher protected t-test is considered inferior to the Ryan test and the Tukey test because it cannot control the inflated Type I error very well (Toothaker, 1993), not because any psychologists or educators made a terribly wrong decision based upon the Fisher protected t-test. Pillai-Bartlett statistic is considered superior to Wilk's Lambda and Hotelling-Lawley Trace because of much greater robustness against unequal covariance matrices (Olson, 1976), not because any significant scientific breakthroughs are made with the use of Pillai-Bartlett statistic. For Peirce this kind of self-referent deduction cannot lead to progress in knowledge. Knowing is activity which is by definition involvement with the real world (Burrell, 1968).

Actually, statistics is by no means pure mathematics without interactions with the real world. Gauss discovered the Gaussian distribution through astronomical observations. Fisher built his theories from applications of biometrics and fertilizer. Survival analysis or hazard model are the fruit of medical and sociological research. Item response theory was developed to address the issue of reducing test bias. For Peirce, deduction alone is a necessary condition, but not a sufficient condition of knowledge. Instead, abduction, deduction and induction must work together.

Induction

Induction introduced by Francis Bacon is a direct revolt against deduction. Bacon (1620/1960) found that deductive reasoners reply on the authority of antiquity (premises made by masters), and the tendency of the mind to construct knowledge-claims out of itself. By using a similar metaphor introduced by anthropologist Clifford Geertz, Bacon criticized deductive reasoners as spiders for they make a web of knowledge out of their own substance. Although the meaning of deductive knowledge is entirely self-referent, deductive reasoners tend to take those propositions as assertions.

As mention before, propositions and assertions are not the

same level of knowledge. For Peirce abduction and deduction only gives propositions, but self-correcting induction gives the support of assertions. Carnap took Peirce's notion that induction is self-corrective and devoted efforts in building a comprehensive system of inductive logic (Tursman, 1987). However, we should be cautious to over-generalize induction as the salvation of deduction.

Inductive logic is based upon the notion that probability is the relative frequency in long run and a general law can be concluded based on numerous cases. For example,

A_1, A_2, A_3 ... A_{100} are B.

A_1, A_2, A_3 ... A_{100} are C.

Therefore, B is C.

Induction is inconclusive in infinite time.

Hume (1777/1912) argued that things are inconclusive by induction because in the infinite time there are always new cases and new evidence. Induction can be justified, if and only if, instances of which we have no experience resemble those of which we have experience. Take the previous argument as an example. If A_{101} is not B, the statement "B is C" will be refuted. Hume even used more radical examples such as nature may change its course. My examples are from sociology and economics.

Based on the case studies in the 19th century, sociologist Max Weber (1904/1976) argued that capitalism could be developed in Europe because of the Protestant work ethic; other cultures like the Chinese Confucianism are by essence incompatible with capitalism. However, after World War Two, the emergence of Asian economic powers such as Taiwan, South Korea, Hong kong and Singapore disconfirmed the Weberian hypothesis.

We never know when a regression line will turn flat, go down or go up. Even inductive reasoning using numerous accurate data and high power computing can go wrong, because predictions are made only under certain specified conditions (Samuelson, 1967). Due to American economic problems in the early '80s, quite a few reputable economists made gloomy predictions about the U.S.

economy such as the takeover of American economic and technological throne by Japan. By the end of the decade, Roberts (1989) concluded that those economists were wrong; on contrary to those forecasts, the U.S. enjoyed the longest economic expansion in its history.

Induction is undefinable in a single case.

Second, induction suggests the possible outcome in relation to events in long run. This is not definable for an individual event. To make a judgment for a single event based on probability like "your chance to survive this surgery is 75 percent" is nonsense. In actuality, the patient will either live or die (50%). Also, this is why people in Hong Kong are very anxious about the construction of a nuclear plant in Daya Bay, South China, even though the statistic released by the Chinese government shows a very low probability of accident. In a single event of nuclear melt-down, the chance of survival is absolutely zero.

Induction generates empirical laws but not theoretical laws.

Third, Carnap, as an inductive logician, knew the limitation of induction. Carnap (1952) argued that induction may lead to the generalization of empirical laws, but not theoretical laws. For instance, even if we observe thousands of stones, trees and flowers, we never reach a point at which we observe a molecule. After we heat many iron bars, we can conclude the empirical fact that metals will bend when they are heated. But we will never discover the physics of expansion coefficient in this way. Peirce (1900/1960) held a similar position: Induction cannot furnish us with new ideas because observations or sensory data only lead us to superficial conclusions but not the "bottom of things." (p.878)

Induction is based on generality and law of large numbers.

Nonetheless, for Peirce induction still has validity. Contrary to Hume's notion that our perception of events are singular or devoid of generality, Peirce argued that the existence we perceive must share generality with other things in

existence. Peirce's metaphysical system resolves the problem of induction by asserting that the data from our perception are not reducible to discrete, logically and ontologically independent events (Sullivan, 1991).

In addition, for Peirce all empirical reasoning is essentially making inferences from a sample to a population; the conclusion is merely probably (never certainly) true and merely approximately (never exactly) (O'Neill, 1993). Forster (1993) justified this view with the Law of Large Numbers. On one hand, we don't know the real probability due to our finite existence. However, given a large number of cases, we can approximate the actual probability. We don't have to know everything to know something. Also, we don't have to know every case to get an approximation. This approximation is sufficient to fix our beliefs and lead us to further inquiry.

Conclusion

In summary, both deduction and induction have different merits and shortcomings. For Peirce a reasoner should apply abduction, deduction and induction altogether in order to achieve a comprehensive inquiry. Abduction and deduction are the conceptual understanding of a phenomena, and induction is the quantitative verification. At the stage of abduction, the goal is to explore the data, find out a pattern, and suggest a plausible hypothesis with the use of proper categories; deduction is to build a logical and testable hypothesis based upon other plausible premises; and induction is the approximation towards the truth in order to fix our beliefs for further inquiry. In short, abduction creates, deduction explicates, and induction verifies.

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